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Cluster X-ray Luminosity Evolution

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Abstract. Whether the X-ray luminosities of clusters of galaxies evolve has been a contentious issue for over ten years. However, the data available to address this issue have improved dramatically as cluster surveys from the ROSAT archive near completion. There are now three samples of nearby clusters and seven distant cluster samples. We present a uniform analysis of four of the distant cluster samples. Each exhibits highly statistically significant luminosity evolution. We combine three of these samples to measure the high redshift cluster X-ray luminosity function with good statistics that shows the nature of the evolution.

1. Introduction

Evidence for evolution of the luminosities of clusters of galaxies came originally from The Einstein Extended Medium Sensitivity Survey (EMSS) (Gioia et al. 1990; Henry et al. 1992). These studies found that the co-moving number density of high luminosity clusters is smaller in the past than at present. Although the EMSS was the first X-ray survey capable of finding clusters at high redshifts (here defined to be > 0.3), hence the first able to search for evolution, it did have some limitations. Perhaps the most severe was the relatively small size of the statistical sample, 67 objects. This limitation was compounded by the soft energy band of the EMSS, 0.3 - 3.5 keV caused by the use of focusing optics. Consequently there was virtually no overlap with almost all previous work in X-ray astronomy (mostly in the 2 - 10 keV band) that might have been used to augment the sample. Thus all evidence for evolution, in particular the comparison of low and high redshift X-ray luminosity functions (XLFs), had to come from within the EMSS itself. Since there were only about 20 objects each in the low and high z bins, the statistical significance of the result was only 3σ . Consequently, the measurement of evolution did not enjoy universal acceptance.

The advent of the ROSAT All-Sky Survey (RASS) and Pointed Program has provided a new opportunity to study cluster luminosity evolution. The RASS provided the huge solid angle required to construct low z samples containing hundreds of objects. The local XLF is now determined very reliably, with good agreement among three samples (Ebeling et al. 1997, BCS; De Grandi et al. 1999, RASS1 BS; Böhringer et al. 2001, REFLEX). The RASS is also being used to find very luminous ($> 10^{45}$ erg s $^{-1}$) clusters, which because they are so rare also requires extremely large solid angles in order to find substantial numbers of them (Ebeling, Edge, & Henry 2001, MACS). The ROSAT Pointed

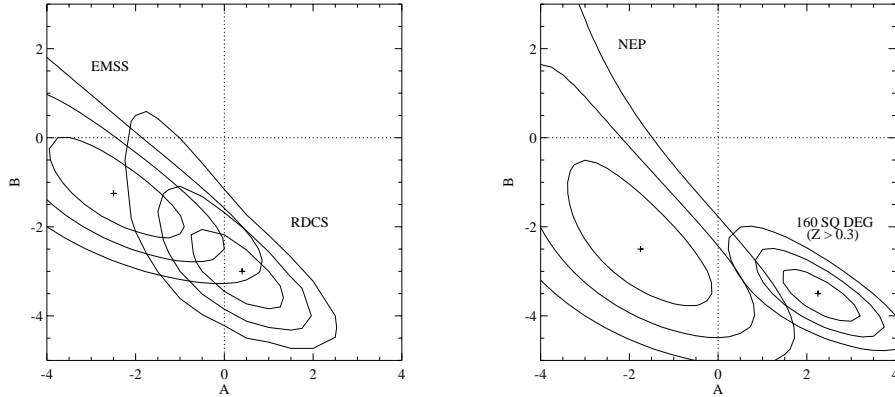


Figure 1. (left) One, two and three σ contours of the AB model fit to the EMSS and RDCS surveys. Figure 2. (right) One, two and three σ contours of the AB model fit to the 160 deg² $z > 0.3$ and NEP surveys.

Program enables the construction of EMSS - like surveys. There are at least four such surveys specifically tailored to finding distant clusters (the latest references are Nichol et al. 1999, Bright SHARC; Vikhlinin et al. 2000, 160 deg²; Rosati et al. 2000, RDCS; Jones et al. 2000, WARPS). Finally, we are using the RASS data around the North Ecliptic Pole to construct a survey that is both as deep as the pointed surveys and is also contiguous (see Henry et al. 2001 for an overview, NEP).

2. Uniform Analysis of Four High Redshift Cluster Samples

Each of the surveys mentioned in the introduction has a unique selection function that must be removed in order to compare them. The usual method, plotting luminosity functions, does not use all the information available. Since the evolution seems to be a lack of objects at high redshifts, there is nothing to plot if the objects are not there. Instead we perform maximum likelihood fits of four high redshift samples to the AB model introduced by Rosati et al (2000). In this model the XLF is $n(L, z) = n_0(z)L^{-\alpha}e^{-L/L^*(z)}$, with $n_0(z) = n_0[(1+z)/(1+z_0)]^A$ and $L^*(z) = L_0^*[(1+z)/(1+z_0)]^B$. Note that n_0, α, L_0^* , and z_0 are not fit, but come from a low redshift XLF, in this case the BCS since it has the lowest normalization of the three determinations thus yielding the least evolution. No evolution in this model is the point $A = B = 0$. Note further that a maximum likelihood fit incorporates the information provided by any “missing” high redshift clusters. We assume that $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$ to be consistent with previous work.

We show the results of the fits in Figures 1, 2, and 3. All four samples exhibit luminosity evolution at the $>> 3\sigma$ level. Figure 3 shows that the agreement among three of the surveys is approximately at the 1σ level but that the agreement with the fourth is marginal. More work will be required to determine whether this disagreement is real or results from the specific model fitted. In

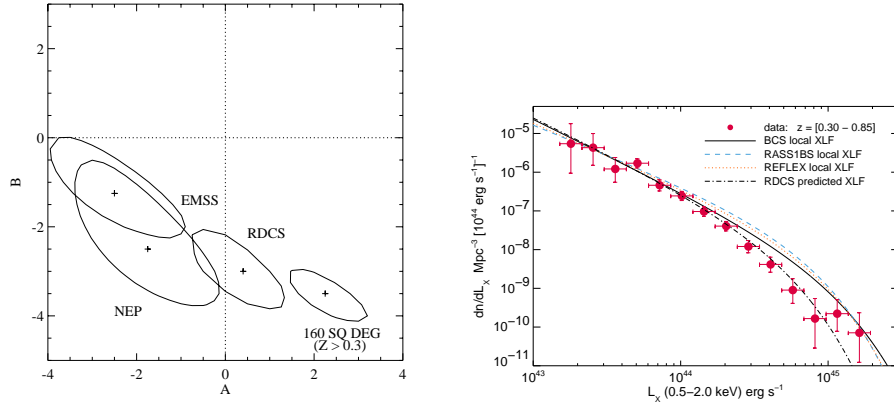


Figure 2. (left) One σ contours of the AB model fit to the EMSS, RDCS, NEP and 160 $\text{deg}^2 z > 0.3$ samples. The first three surveys agree at this level when fit to this specific model. Figure 4. (right) High redshift cluster luminosity function determined from the combined EMSS, NEP and 160 deg^2 surveys compared to three local luminosity functions. The RDCS best fit AB model predicts the high redshift function well with no adjustable parameters.

particular, we have forced the best fitting low redshift XLF onto the fit without considering the errors in its parameters.

3. High Redshift Cluster Luminosity Function from Three Samples

The fits described in Section 2 show that cluster luminosity evolution is occurring. We construct the high z XLF from the sum of the EMSS, NEP, and 160 deg^2 samples in order to obtain a higher statistics non parametric description of that evolution. The overlap on the sky of these three samples is about 5%, so we have corrected statistically for double counting since the corrections are not large. We compare this high z XLF to the three low z XLFs in Figure 4. The high z XLF, which has a median redshift of 0.43, falls a factor of two below the average of the three low z XLFs at a luminosity of $2 \times 10^{44} \text{ erg s}^{-1}$ in the 0.5 - 2.0 keV band. Further the AB model fit to the RDCS data alone also provides a reasonable description to the XLF of the combined sample. We emphasize that the RDCS model is a prediction determined independently and has no adjustable parameters.

4. Conclusions

A preliminary analysis of the MACS bright sample shows that this sample also exhibits luminosity evolution at $> 3\sigma$. Thus there are now five nearly independent samples of high z clusters that find evolution: EMSS, 160 deg^2 , RDCS, NEP, and MACS. We feel that the salient question is no longer “does cluster

evolution exist?”, but rather “what is its amplitude as a function of redshift and luminosity?”.

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